Particle Background Estimates for GLAST

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7 April 1997
rev. 3 Nov 1997, new baseline geometry ($1.6 \times 1.6 \times 0.75$ m)

I have taken as my task the estimation of the total flux of particles capable of depositing a few MeV or more within the volume of the GLAST detectors. The lowest energy particles contribute only to the threshold rate in the outer portions of the instrument, while the highest energy generate the hadronic showers whose rejection is essential to the success of GLAST. I have tried to estimate particle rates from galactic and anomalous cosmic rays, trapped radiation, solar energetic particle events, and splash albedo. Some of these estimates are derived using the CREME96 code, developed by the Cosmic Ray Physics Section of the Gamma & Cosmic Ray Astrophysics Branch at the Naval Research Lab. Other estimates are derived from data taken in similar orbits or scaled from observations using crude rules of thumb. These estimates will be updated as new data become available.

I have assumed that the GLAST instrument is contained in a box, $1.6 \times 1.6 \times 0.75$ m in dimension, which gives a geometry factor of 31 m^2 sr. Because the tracker is essentially transparent to GCR (with ~3.2 g/cm^2 of Pb at vertical incidence), it is simple to calculate particle rates in the calorimeter only, which I have taken to be $1.6 \times 1.6 \times 0.2$ m in dimension, for a geometry factor of 20 m^2 sr. Thus ~2/3 of an isotropic particle flux that passes through any part of GLAST passes through the calorimeter.

The most useful information in this document is contained in the final two tables. The first gives particle rates in a variety of solar and geomagnetic conditions for a nominal GLAST orbit of 600 km at 28.5 deg inclination. The second gives a number of rules of thumb for estimating particle rates in other orbits or at other times in the solar cycle, or for estimating the relative contributions to the total particle rate

Galactic Cosmic Rays and Anomalous Cosmic Rays

The galactic cosmic rays are the dominant source of charged particle background for the ~90% of GLAST's orbit that is outside the trapped-particle belts. I have taken the cosmic ray beam to contain elements from H to Ni (Z = 1-28). For interest, I have also calculated GCR rates at a few breaks in the abundance ratios, viz. C ($Z \geq 6$), Ne ($Z \geq 10$), and Fe group ($24 \geq Z \geq 28$). The GCR rate is higher at solar minimum, lower at solar maximum. CREME96 uses GCR spectra at 1 AU taken from the literature, corrects for modulation by the solar wind as appropriate for the solar cycle, filters them as appropriate through Earth's magnetosphere, and reports an orbit-averaged particle rate. I have estimated rates at both solar minimum and maximum, assuming quiet geomagnetic conditions, using the 28.5 deg, 450 km orbit pre-calculated for CREME96. The pre-calculated geomagnetic transmission function is derived from ray-traced Monte Carlo particle trajectories, and is the most precise estimate available through CREME96. I studied the scaling with altitude by simulating orbits from 400 to 650 km in 50 km steps with transmission functions calculated at run time. The rates in the table below are scaled to a nominal GLAST altitude of 600 km.

The estimate of the *maximum* GCR rate seen by GLAST is derived by searching for the geographic position with the lowest western cutoff rigidity (the direction of easiest access for positively charged particles), then sampling cutoff rigidities over all look angles, weighted by solid angle, to generate a geomagnetic transmission function for the location. This transmission function can then be used for maximum rate estimates for both GCRs and SEPs.

Note that the particle rates given here are merely rates of particles entering the GLAST volume. I have ignored the effects of spallation interactions and ranging-out on rates deep in the calorimeter. By default, CREME96 includes the anomalous cosmic rays (interstellar neutrals ionized by solar uv, entrained in the solar wind, then accelerated at the solar wind termination shock), but they make a negligible contribution to the particle backgrounds in GLAST.

Trapped Particles

Electrons, protons, and heavy ions are trapped in the magnetosphere, generally at altitudes far above a reasonable GLAST orbit. The offset of the geomagnetic dipole brings the particle belts to low altitudes over the south Atlantic, the South Atlantic Anomaly (SAA). In the belts, electrons dominate below a few MeV, with a very steep number spectrum ($\sim K^{-4}$, K = kinetic energy), and can therefore be completely shielded by a couple g/cm^2 of material. *For the moment I have completely ignored the electron contribution.* Protons have a very flat number spectrum ($\sim K^0$) that breaks at a few tens of MeV; they are not trapped above several hundred MeV.

At a given altitude, trapped proton fluxes are *lower* at solar maximum than at solar minimum, because the atmosphere expands at solar max and sweeps particles out of the belts. The variation with solar cycle is significant: SAMPEX (520 x 680 km, high-inclination orbit) saw an increase of a factor of ~3 from 1992 (well after solar max) to 1996 (solar min) (R. Mewaldt, Caltech, personal communication). Calculations using the GSFC AP8 model suggest a smaller factor, with solar max ~½ of solar min. The difference may however be the result of the appearance of transient belts at magnetic latitudes above those reached by GLAST, so for the moment I've used the scale factor from AP8.

The trapped radiation is highly directional, so the rates listed below apply as an average over the whole of GLAST. Rates may be substantially higher on a given face of the telescope than on the opposite face. Because the energy spectrum of trapped particles is so soft, the spacecraft and the baseplate of the instrument can provide substantial shielding of the detectors in certain attitudes.

The CREME96 code does not yet estimate trapped particle fluxes. The fluxes given below are estimated from a calculation in a 28.5 deg, 500 km orbit performed by Tony Armstrong (SAIC, Oak Ridge TN). I have crudely scaled the calculated flux up to a 600 km orbit using a rule of thumb derived from the AP8 trapped proton models, which are considered *unreliable* below 800 km but are the best available at this date. Scaling rules for altitude changes will be available from OSSE CPM data in Summer 1997, following the GRO reboost from 430 km to 515 km.

Solar Energetic Particles

Solar energetic particles (SEP) are primarily protons accelerated by interplanetary shocks from large coronal mass ejections (at least this is true of the large, long-duration events we care about). While such events are more likely during solar maximum, they may indeed occur at any phase of the solar cycle. SEP events can produce very high particle fluxes, but the energy spectrum is relatively soft: outside the magnetosphere SEP fluxes dominate GCR fluxes only below several hundred MeV/nuc. In a 28.5 deg orbit, SEP events are well shielded by the magnetosphere and, except in the most unfavorable geomagnetic conditions (i.e. only if an event occurs when the GLAST is at the minimum cutoff rigidity in a stormy magnetosphere), SEP rates seen by GLAST should be ~10% of the GCR rate.

I estimated the effects of SEP events using CREME96 "Peak Flux", "Worst-Day", and "Worst-Week" models, assuming a stormy Earth's magnetosphere, which transmits significantly greater particle fluxes than does a quiet magnetosphere. Geomagnetic storms are often associated with SEP events. The SEP models are based on satellite measurements over the last two solar cycles, which fortunately for us contained an unusually strong particle event in October 1989. I used the peak flux model and the orbit-average stormy geomagnetic transmission function to estimate the "peak" SEP rate seen by GLAST for a random spot in the orbit, and I used the peak flux model and the minimum cutoff rigidity, as established by ray-tracing, to estimate the peak rate in the most unfavorable geomagnetic condition, a rather unlikely event.

Particle Albedo

There is substantial proton (and neutron) albedo in LEO, where here I call "albedo" any particles outside the radiation belts with energies below the cutoff rigidity and trajectories generally upward or horizontal. Calculations for a variety of orbits have been performed, but high quality data are sparse. Calculations for LDEF (480 km nominal, 28.5 deg orbit) suggest the integral flux of albedo protons above 10 MeV is equal to the integral transmitted GCR flux (i.e. the rate of stuff coming "up" is the same as the rate going "down"), but the spectrum of the albedo is fairly soft, with nothing above a few GeV. A study of albedo flux as a function of magnetic latitude is underway with SAMPEX data (M. Looper, Aerospace Corp., personal communication). In the estimates below, I have used the LDEF calculation, but I will replace these values with the SAMPEX results when they become available. So I give the following warning: ***Splash albedo may indeed be an important source of low-energy proton background for GLAST; then again, it may not.***

Particle rates in GLAST

The following table gives fluxes and counting rates for galactic cosmic rays at solar minimum and solar maximum as averages over many orbits ("orbit averaged") and as a peak rate at the point in the orbit with the greatest geomagnetic access ("orbit worst case"). The orbit is 28.5 deg at 600 km.

	Solar minimum GCR		**Solar maximum GCR**	
	Orbit averaged	**Orbit worst case**	**Orbit averaged**	**Orbit worst case**
Flux (m^{-2} sr^{-1} s^{-1})	130	510	100	350
Calorimeter rate (s^{-1})	2600	10000	2000	7000
Full GLAST rate (s^{-1})	**4000**	**16000**	3100	11000

The following table gives the fluxes and counting rate estimates for trapped particles during solar minimum and for solar energetic particles at the peak of an event. The "SAA averaged" value is the rate averaged over all time spent in the SAA (which I've defined to be exactly 10% of an average day; the true value is closer to 12%), while the "SAA maximum" value is the peak rate at some point in the SAA. The "orbit averaged" peak SEP value is meant to simulate the occurrence of a worst-case SEP event at a random spot in the orbit, while the "orbit worst case" value simulates the occurrence of a worst-case SEP event at the point in the orbit with greatest geomagnetic access. The orbit is again 28.5 deg at 600 km.

	Trapped particles, solar min		**Peak SEP event**	
	SAA averaged	**SAA maximum**	**"Orbit averaged"**	**Orbit worst case**
Flux (m^{-2} sr^{-1} s^{-1})	1.3×10^6	8.6×10^6	14	280
Calorimeter rate (s^{-1})	2.6×10^7	1.7×10^8	280	5600
Full GLAST rate (s^{-1})	4.0×10^7	2.7×10^8	430	8700

Several different average or peak particle rates are interesting and can be estimated from the preceding tables. *The flux of albedo protons might be approximately equal to the sum of the GCR and SEP flux, so in the estimates of the total particle rates in the table below, I have included this doubling factor in the values given in square brackets.* ***This may be an overestimate.*** I will revisit these numbers when SAMPEX data are available. The effect of the soft-spectrum albedo on the GLAST trigger must be investigated.

Configuration	**Terms**	**Rate (s^{-1})**
Typical rate (solar min)	Solar minimum GCR orbit-averaged + albedo	4000 [8000]
Typical rate (solar max)	Solar maximum GCR orbit-averaged + albedo	3100 [6200]
Typical rate (SEP event, solar min)	Solar min GCR orbit-averaged + peak SEP orbit-averaged + albedo	4400 [8900]
Worst case rate (solar min, quiet sun)	Solar min GCR orbit worst case + albedo	16000 [32000]
Worst case rate (SEP event, solar min)	Solar min GCR orbit worst case + peak SEP orbit	25000 [50000]

Worst case rate (peak of SAA)	worst case + albedo Trapped particles SAA max + negligible terms	2.7×10^8

Rules of thumb for 28.5 deg LEO

Change in transmitted GCR flux at solar maximum: Change in transmitted GCR flux with altitude: Maximum GCR flux during orbit:	–20%, relative to solar minimum. +3.5% per +50 km. ×4, relative to orbit average.
Change in trapped CR flux at solar maximum: Change in trapped CR flux with altitude:	×½, relative to solar min at same altitude. ×2-3 per +50 km.
Peak transmitted SEP flux, "orbit averaged": Peak transmitted SEP flux, worst case in orbit: Peak transmitted SEP flux, quiet magnetosphere: Worst-Day transmitted SEP flux, "orbit averaged": Worst-Week transmitted SEP flux, "orbit averaged":	10% of orbit-average GCR. ½ of orbit-maximum GCR. 66% of peak SEP, stormy magnetosphere. 3% of orbit-average GCR. 3% of orbit-average GCR.
Albedo proton rate:	Same as transmitted GCR rate (?).